INTRODUCTION

A major portion of the energy produced in the world today comes from burning liquid hydrocarbon fuels in the form of droplets. Understanding the fundamental physical processes involved in droplet combustion is not only important in energy production but also in propulsion, the mitigation of combustion-generated pollution, and the control of fire hazards in handling liquid combustibles. The second space-based droplet combustion investigation to date, the Fiber Supported Droplet Combustion (FSDC–2) will continue to study fundamental phenomena related to liquid-fuel-droplet combustion in air. Pure fuels and mixtures of fuels will be burned as isolated single droplets with and without forced-air convection. The FSDC–2 investigation will be conducted in the Microgravity Glovebox (MGBX) facility of the Shuttle Spacelab during the first Microgravity Science Laboratory (MSL–1) mission in March 1997.

SCIENCE OVERVIEW

The classical theory of burning assumes that for an isolated, single-fuel droplet, the gas-phase combustion processes are much faster compared with the droplet surface regression rate and that the liquid phase is at a uniform temperature that corresponds to its boiling point. This theory, known as the "d-square law" model, contains many other simplifying assumptions and predicts that the square of the droplet diameter decreases linearly with time (fig. 1). The rate at which a droplet burns is important in many applications such as in internal combustion and jet engines.

Recent, more advanced models, which still assume spherically symmetric combustion in a quiescent medium, predict that both liquid-phase and gas-phase unsteadiness exist during a substantial portion of a droplet's burning history (fig. 1), thus affecting the instantaneous and average burning rate. Ground-based, low-gravity experimental data, although confirming some of these theoretically predicted trends, are severely hampered by the limited low-gravity time available in drop towers. Transient processes such as soot formation, coagulation, and escape from the flame envelope, as well as relative drop/gas velocities complicate the interpretation of these experimental results. Well-defined, spherically symmetric droplet burning data are needed to validate the theoretical models (fig. 2).

Multicomponent droplet burning studies are motivated by the need to understand the burning characteristics of blended fuels and liquid hazardous wastes. Depending on the relative concentrations and volatilities of the components and their miscibility, multicomponent fuels exhibit peculiar, unsteady burning characteristics. Under certain conditions that are still not well understood, the droplet internal temperature can exceed the homogeneous nucleation temperature of a fuel component, leading to the formation and growth of a vapor bubble in the droplet. This rapidly growing vapor bubble ultimately shatters the surrounding liquid fuel envelope into smaller fragments that burn more efficiently because of their increased surface area

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The importance of liquid species diffusion in multicomponent droplet burning has also been recognized. In normal-gravity experiments, buoyancy may destroy spherical symmetry by inducing convective mixing in the gas and liquid phases; therefore, microgravity experiments help to clarify the phenomena that occur during multicomponent droplet burning. Product dissolution can change an initially pure fuel into a multicomponent fuel, a behavior observed in alcohol fuels when the combustion-generated water is absorbed by the fuel, leading to nonlinear burning. Microgravity experiments facilitate the study of these phenomena.

The first Fiber Supported Droplet Combustion investigation was conducted in the Glovebox facility of the Shuttle Spacelab during the Second United States Microgravity Laboratory (USML–2) mission in October 1995 and provided valuable information about the droplet combustion phenomena. The results obtained from FSDC–1 demonstrated that data for fuel droplets as large as 5 mm in diameter are helpful for testing droplet burning theories. These first experiments verified predictions that methanol droplets would be extinguished at diameters that increase with increasing droplet diameter. In comparison with numerical computations, the experimental data overpredicted the extinction diameter. Therefore, to reduce this discrepancy, the flame radiant energy loss, the importance of which increases with increasing droplet diameter, is now actively being incorporated into existing computational and analytical droplet combustion models. Consequently, FSDC–2 will utilize radiometers to quantify the radiant flame energy. Adding water to methanol on FSDC–1 reduced the burning rate, increased the nonlinearity of the variation of the square of the droplet diameter with time, and increased the extinction diameter. The numerical model qualitatively reproduces each of these phenomena, although the predicted rates are somewhat larger and the extinction diameters are less than those observed. Methanol-dodecanol droplet mixtures experienced staged combustion in which the methanol predominately burned first and became largely depleted in a surface layer of the liquid; then, the flame contracted and the droplet shattered as a result of vapor growth within it. In addition, the quasi-steady burning rate of the heptane-hexadecane mixtures appeared to decrease with increasing droplet diameter, and heavy sooting was observed but without the formation of soot shells for the largest of these droplets. Forced convective flow around methanol droplets increased the burning rate and produced a ratio of downstream to upstream flame radius that remained constant as the droplet increased. This trend was in agreement with earlier results obtained at higher convective velocities for smaller droplets that had larger flame standoff ratios. To extend the range of FSDC–1 testing, the FSDC–2 test matrix will include higher order alkane and alcohol (decane and ethanol, respectively) pure fuels and different binary fuel concentrations for methanol/water and heptane/hexadecane mixtures. Also, a wider range of fuel-droplet diameters will be investigated.

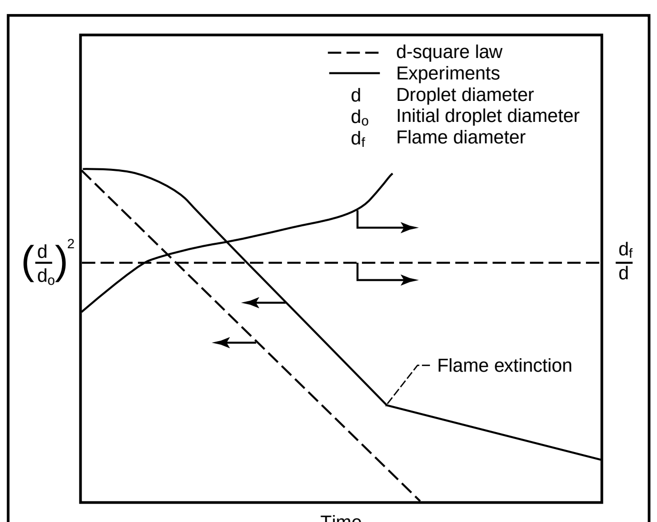

Figure 1.—Classical description of droplet combustion and experimental observation.

OBJECTIVES

The FSDC–2 test matrix comprises several separate science investigations, the objectives of which follow:

Pure Fuel-droplet Combustion

N-heptane and n-decane single-droplet combustion with no forced flow: N-heptane and n-decane are alkane fuels that have an extensive data base containing their combustion characteristics in normal gravity. They have a tendency to soot, and their measured burning rates vary depending on the initial droplet size and the experimental procedure used. Speculation on the cause of this variation is that soot shells form between the droplet surface and the flame and interact with the local flow and temperature field. The objective is to investigate transient burning rates, flame unsteadiness, and soot shell dynamics by using large droplets to allow expanded time and length scales.

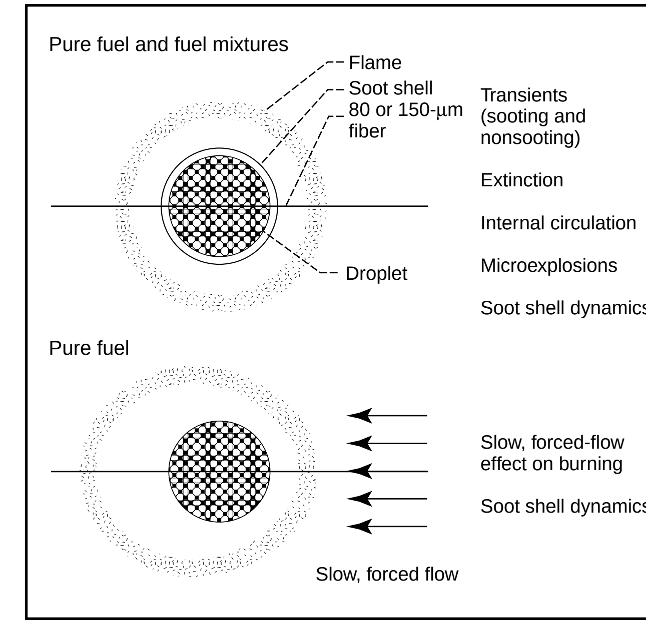

Figure 2.—Physical phenomena.

N-heptane and n-decane single-droplet combustion in a slow convective flow and flame shapes: The objective is to obtain data on droplet burning rates in a slow, well-defined convective field and to observe the behavior of the soot shell. The results will be compared with theoretical predictions.

Methanol and ethanol single-droplet combustion with no forced flow: In drop tower tests at the NASA Lewis Research Center and in FSDC–1, the burning rates of methanol droplets in air were observed in low gravity to continuously decrease with time because of water absorption within the droplet . Water absorption is also predicted to affect higher order alcohols such as ethanol which can become an azeotropic mixture with the addition of water. Ground-based, low-gravity facilities limit the size of the droplets to a maximum diameter of 1 mm. The objective here is to investigate the effect of initial droplet size on the transient burning rates and to observe the extinction phenomenon for longer diameter alcohols than those conducted on FSDC–1.

Bicomponent, Miscible, Fuel-Droplet Combustion

N-heptane/hexadecane miscible binary-fuel, single-droplet combustion with no forced flow: Fuel mixture components are selected to vary widely in volatility so that the preferential evaporation effects are exaggerated. The objectives are to study the transient burning histories, soot dynamics, and flame behaviors, especially the sudden contraction from the rapid buildup of the hexadecane mass fraction at the liquid surface.

Methanol-water mixture single-droplet combustion with no forced flow: Normal-gravity and reduced-gravity droplet burning with various concentrations of water in methanol have shown that increasing water concentration lowers the initial and final burning rates. Furthermore, the water concentrations measured for extinguished droplets remained constant irrespective of the initial water concentration. Thus, the primary objective is to study the effect of water dissolution on the burning characteristics of alcohol fuels.

For all burning fuel droplets, radiative emissions measurements will be taken to quantify the heat loss from the flames.

HARDWARE DESCRIPTION

The FSDC–2 hardware consists of an experiment module and a separate parts box. The experiment module contains the fiber support, deployment needles, hot-wire igniter arm, and fuel cartridges. The bottom section of the module houses the electronics that control the experiment. There are fourteen different fuel cartridges, each feeding a designated fuel line. The cartridges are operated individually to feed a single-pair of needles and to form a single droplet at various set locations along the support fiber. The supporting silicon carbide fibers are 80 or 150 µm in diameter.

A fan located on one end of the experiment module draws air along the fiber through a metal screen located on the other end. Flow straighteners positioned in front of the fan produce a uniform flow. Two radiometers mounted in the module record radiative emissions from a droplet flame. One has a broadband filter and the other, a waterband filter. The radiometer data recorded by a video camera are displayed on a light-emitting diode (LED) box. During combustion, the droplet size is recorded by a video camera attached to the Glovebox-supplied microscope. The backlight is provided by a linear array of redlight-emitting diodes. The flame images are captured via another CCD camera mounted to the front door of the Glovebox.

OPERATIONAL SEQUENCE

The Shuttle payload crew will set up the FSDC–2 experiment inside the MSL–1 Glovebox, remove the front cover, and install the fiber support and igniter arm in the experiment module. A box will also be positioned inside the Glovebox to display the radiometer and fan flow data. Then, they will hook up the power cables to energize the experiment. Depending on the test being performed, the crew will select the appropriate fuel cartridge and attach it to the fuel feed line.

The droplet-viewing camera with the microscopic lens and the flame-viewing camera will then be installed and focused at the appropriate location along the fiber. At this point, the experiment is ready for activation. Turning the knob on the fuel cartridge to a preset number of clicks will dispense measured amounts of fuel onto the fiber. The dispensing needles will be separated by a small distance to stretch the droplet and then the needle arms will be swung open to deploy the droplet onto the fiber. Following deployment, the igniter will be energized to ignite the droplet and will then be retracted after ignition. When the experiment test matrix demands forced convection, the fan will be turned on immediately following ignition. The backlit droplet image, the flame view, and the display box readings will be recorded on video tapes during each experimental run.

POSTFLIGHT DATA ANALYSIS

The data obtained from the FSDC–2 investigations are the recorded images of the droplet, flame, and display box readings. A computer-based image analysis system will be used to obtain data for droplet diameter, flame diameter, and radiation emission versus time. The calibrated fan settings provide the forced-flow velocity. From these data, the burning rates for different fuels under different environmental conditions will be obtained. These experimental results will be compared with existing theoretical models and previously obtained ground-based data, and they will provide data for the development of new burning rate and extinction models.

SUMMARY

The FSDC–2 investigations will provide scientists fundamental data on droplet burning characteristics for pure fuels and fuel mixtures burned as isolated droplets with and without forced flow. These data for droplet burning rates, flame dynamics, and radiation emissions will help to validate basic theoretical models.

The FSDC–2 investigation is sponsored by the NASA Lewis Research Center, whose researchers are working in cooperation with investigators from industry and academia. The Center has been involved in aerospace propulsion, power, and materials research since its opening in 1941 and has been involved in microgravity research since the early 1960's. Lewis is the NASA lead center in microgravity combustion and fluids science research with over 40 ongoing projects.

ABOUT THE GLOVEBOX

The Glovebox (GBX) is an ergonomically sound multiuser facility developed for conducting experiments on Spacelab or in the shuttle middeck. It has been designed to handle biological, fluids, combustion, and materials science experiments. It can contain powders, splinters, liquids, or bioparticles that could result from such operations, whether accidentally or purposefully. Thus a crew member can carry out operations involving small quantities of toxic, irritating, or potentially infective materials that must not be allowed to contaminate the spacecraft atmosphere. FSDC–2 uses the GBX power supply, color video cameras, and containment capability. FSDC–2 is one of five GBX investigations to fly on MSL–1.

The Glovebox was developed by Teledyne Brown Engineering (Huntsville, Alabama) and Bradford Engineering (the Netherlands) under contract to NASA Marshall Space Flight Center.

DESIGN CHARACTERISTICS

- Total weight: 31 lb (14 kg)
- Power: 40 W maximum
- Fuels: n-heptane, n-decane, methnol, methanol/water, ethanol, n-heptane/ n-hexadecane
- Flow velocity: 0 to 25 cm/s
- Data: Backlit images of droplet and flame, radiometer readings, Glovebox ambient temperature, humidity level, and local acceleration levels

FSDC–2 TEST MATRIX

Fuel	Droplet size, mm	Flow
n-heptane	4-6	no
n-heptane	4-6	yes
n-decane	2-5	no
n-decane	4	yes
methanol	2-7	no
ethanol	3-6	no
methanol/water mixtures (85/15 & 70/30)	2-5	no
n-heptane/hexadecane (95/5 & 80/20)	2-5	no

MISSION OBJECTIVES

- Investigate the burning characteristic of pure fuels (n-heptane, n-decane, methanol, ethanol) and fuel mixtures (methanol/water and n-heptane/n-hexadecane) in air under spherically symmetric burning conditions.

- Investigate the effects of slow imposed convective flow on a pure fuel-droplet burning rates.

- Investigate the degree of radiative emissions emanating from a burning droplet for a wide range of fuels, droplet diameters and flow rates.

Project Manager

Susan M. Motil
NASA Lewis Research Center
Cleveland, Ohio 44135
(216) 433–8589

Glovebox Investigator

Forman A. Williams
University of California, San Diego
San Diego, California 92037
(619) 534–5492

Co-Investigators

Renato O. Colantonio
NASA Lewis Research Center
Cleveland, Ohio 44135
(216) 433–6370

Frederick L. Dryer
Princeton University
Princeton, New Jersey 08540
(609) 258–5206

John B. Haggard, Jr.
NASA Lewis Research Center
Cleveland, Ohio 44135
(216) 433–2832

Vedha Nayagam
Analex Corporation
Brook Park, Ohio 44142
(216) 433–8702

Benjamin Shaw
University of California, Davis
Davis, California 95616
(916) 752–4130

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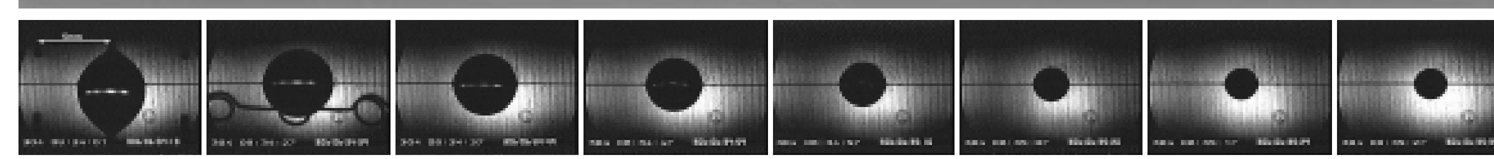

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